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Estimating The Costs Of Global Warming - Comparative Static And Dynamic Approaches

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ESTIMATING THE COSTS OF CLIMATIC CHANGE - COMPARATIVE STATIC AND DYNAMIC APPROACHES

There is considerable scientific evidence to suggest that human activity will lead to significant climatic change over the next fifty years. The most important example is the 'greenhouse effect' which, it has been predicted, will lead to an increase in global mean temperature of up to 4° *C* over the next fifty years[1].

As a result of these predictions there have been numerous calls for policy action aimed at reducing the degree of global warming, primarily by reducing net emissions of the 'greenhouse gases' (primarily carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (NO) methane (CH_4) and chlorofluorocarbons (CFCs)). Some of these proposals, most notably reductions in CFC emissions, involve relatively low costs and have additional benefits, such as reduced damage to the atmospheric ozone layer, sufficient to justify them even in the absence of concerns about global warming. Others, such as reductions in emissions sufficient to stabilize the current atmospheric stocks of CO_2 and CH_4 would involve substantial economic and social costs.

In order to assess the desirability of such proposals, it is necessary to formulate some estimates of the likely costs of climatic change. The simplest approach, adopted in much of the popular debate on the topic, is to catalog likely adverse effects such as the submersion of some Pacific islands, increased severity of monsoons and hurricanes in tropical and sub-tropical areas and the conversion of currently fertile areas into desert. It does not appear that any attempt has been made to convert such a qualitative assessment into an estimate of economic costs. Costs estimated in this fashion would be large.

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[1] The use of the phrase "up to" is significant. There is considerable debate over the likely extent of warming. A minority of scientists claim that there is insufficient evidence to justify any prediction of the likely trend in temperature.

However, such an estimate would be meaningless because of the failure to take into account offsetting benefits. To take the simplest example, the increased severity of monsoons would raise rainfall in many arid areas. Land that is currently desert would become fertile. It is not clear whether the total area of desert would expand or contract.

After seeking to take account of both costs and benefits, economists such as Nordhaus (1991) and Schelling (1991, 1992) have produced estimates suggesting that the net costs of climatic change will be quite small, at least for developed countries such as the United States. Nordhaus estimates the quantifiable net damages at 0.26 per cent of GNP. After quadrupling this estimate to allow for unmeasured costs, he concludes that the cost-justified mitigation policy involves the elimination of most CFC emissions and a 2 per cent reduction in CO_2 emissions relative to their baseline (increasing) trend. The virtual elimination of CFC's has already been ensured because of concerns about their potential effects on ozone depletion. Hence, Nordhaus' conclusion is that no significant new action to mitigate global warming is justified.

Schelling comes to the same conclusion as far as the presently developed countries are concerned. He suggests however, that impacts on less developed countries may be substantial. (Nordhaus avoids consideration of this issue by assuming that the world economy in 2050 will be similar to the US economy today, with agriculture playing a minor role).

These estimates are implicitly derived from an exercise in comparative statics. Climate is treated as an input into production inseparably associated with land in a given region. Other factors such as labor and capital are combined with land and climate to produce goods and services. In long run equilibrium, labor and capital are allocated across regions (and industries) so as to maximize the net value of output. A global change in climate changes the productive characteristics of land in each region. The procedure adopted by Nordhaus and Schelling is, in essence, to estimate the change in the long run equilibrium value of output associated with a climatic change, assuming current endowments of land, capital and technology.

An alternative procedure, more theoretically satisfying, but much more difficult, would be to make a dynamic estimate of the costs and benefits associated with the transition from the current climate (and the associated allocation of resources) to a new long run equilibrium. The difficulties associated with deriving such an estimate are exacerbated, in two ways, by the considerable uncertainty about the likely extent of the rise in global mean temperature and the even greater uncertainty about the pattern of local climatic change. This creates difficulties in choosing the parameters for any dynamic estimate. There is a more fundamental difficulty, however. In modelling the transition path, it is necessary to take account of the fact that decision-makers who determine the allocation of resources are themselves subject to considerable uncertainty concerning the future path of climate.

Given the difficulties associated with the derivation of a dynamic estimate incorporating uncertainty, an effort in this direction could be justified only if there were grounds for supposing that the relatively simple comparative static estimates were systematically biased. The object of the present paper is to show that there are such grounds. First, it is shown that, under reasonable assumptions about the economic role of climate the application of the comparative static method must yield a mean estimate of zero. Second, it is shown that, under the same conditions, dynamic estimates of losses must always be positive.

The central result is that losses will be positive whenever the rate of adjustment required to adapt capital stocks (interpreted broadly to include natural resource stocks) to changing climate is more rapid than the 'natural' rate of adjustment associated with processes such as the depreciation of old capital items and their replacement with new, optimally located, items. In addition, uncertainty about global warming is shown to involve positive costs in the dynamic framework, but not in the comparative static framework.

The damage estimates presented by Nordhaus may be assessed in the light of these results. It is shown that Nordhaus' mean estimate is non-zero solely because they deviate from the comparative static approach in estimating costs associated with sea level changes. A consistent application of the comparative static approach to the available data would yield a mean estimate of zero damage associated with global warming.

In the second part of the paper, a preliminary attempt is made to quantify some of the sources of loss associated with global climatic change in a dynamic framework. Particular attention is paid to capital stocks associated with agriculture and to natural resources.

The Comparative Static Approach

The basis of the comparative static argument for a small net impact from global warming may be summarized as follows. Human productive activity is possible under a wide range of climatic conditions. Hence there is no reason to suppose that a change in climate will have substantial negative effects except in areas that are already marginal because of high temperatures or monsoons. These latter negative effects will be offset by positive effects in areas which are currently marginal because of low temperatures. In order to formalize this argument it is necessary to set out the comparative static approach in more detail.

Assume an aggregate capital stock K and labor force N. There are m regions. In each region, two classes of productive activity may be undertaken. The first class of activity is independent of climate and yields an output $f(K_{i1}, N_{i1})$ in region i, where K_{i1} and N_{i1} are the capital and labor used in region i for the first class of activities. The second class consists of activities that are dependent on climate.

The potential contribution of land area i to production is given by a function $L_i(T_i)$

where T_i is an index of the climate in region i (which may be taken, in the simplest case, to be summarized by mean temperature). The function L_i is assumed to be concave in T_i with a maximum $\bar{L}_i$ at some T_i. Further L_i approaches zero for sufficiently large and sufficiently small T_i. That is, both extremely hot and extremely cold regions are of negligible productive value.

Total output produced in region i is given by

$$Y_i = f(K_{i1}, N_{i1}) + g(K_{i2}, N_{i2}, L_i(T_i)) \tag{1}$$

where K_{i2}, N_{i2} are the capital and labor used in region i for activities in the second class. Note that all differences between regions are assumed to be captured by L_i so the functions f, g are the same for all regions.

Under either optimal planning or a competitive equilibrium there exists a set of capital and labor allocations K^*, N^* such that $Y = \sum_{i=1}^{n} Y_i$ is maximized subject to the constraints $\sum_{i=1}^{n} K_{i1} + K_{i2} = K$, $\sum_{i=1}^{n} N_{i1} + N_{i2} = N$.

The value of this optimal outcome depends on the distribution of temperature. It also depends on the aggregate factor endowments but these will be treated as fixed.

$$Y = \phi(L_1, L_2 \dots L_m) = \phi(T_1, T_2 \dots T_m) = max_{K^*, L^*} \sum_{i=1}^{n} Y_i \tag{2}$$

If all of the regions 1, 2 ... m are identical (except for differences in climate) then Y will depend only on the set $\boldsymbol{T} = \{T_i : i \in 1, 2 \dots m\}$. In particular, it may be of interest to focus on the increasing rearrangement of this set, the sequence $(T^1, T^2 \dots T^m)$ such that $T^1 \leq T^2 \dots \leq T^m$. By the concavity of L, the contribution of climate to production will be least for the extreme values of I and greatest for the intermediate values.

Suppose for simplicity that the elements of T are evenly spaced, that is $T_{i+1} = T_i + \Delta$, $\forall\ i$. Then the effect on $\boldsymbol{T}$ of a uniform increase in all temperatures by Δ may be obtained by deleting T^1 and replacing T^m with $T^m + \Delta$. This effect will be small. In particular suppose that $L(T^1) = L(T^m) = 0$ *i.e.* that both the hottest and coldest regions are of negligible economic value. Then

Proposition 1: A small uniform change Δ will have no effect on Y

More generally we may consider the case where land quality and climate are assumed to vary in a more or less continuous way. In this case the distribution of climate may be represented by a probability distribution $F(T)$. If the distribution F is uniform and both the hottest and coldest regions are of negligible economic value, a small uniform change Δ will have no effect on Y.

This reasoning is not affected by uncertainty. Suppose that there is uncertainty represented by a set of independently and identically distributed random variables η_i about the values of each of the T_i in the discrete case. Suppose once again that the means of the T_i are evenly spaced and that $L(T) = 0$ for all T in the support of both $T^1 + \eta^1$ and $T^m + \eta^m$. Then the effect of a shift ε is zero, exactly as in the deterministic case.

Similarly, it does not matter that the change in temperature is unlikely to be uniform. Some areas will have a greater than average increase in mean temperature, others a lower than average increase, or even a decrease. Provided there is no systematic pattern to this variation, the argument presented here remains valid. The only important possibility is that global warming might act to increase (or decrease) the variation in the distribution of temperatures as would occur if warming is greatest (least) at the Equator, and least (greatest) in high latitudes.

The type of shift that is likely to occur in the new equilibrium may be estimated using the following back-of-the-envelope approach. From the isotherms observed under the existing temperature distribution, a rise in mean annual temperature of about 3° C is associated with a move of about 4.5 degrees of latitude or 500 km[2] towards the equator.

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[2] In calculations of this kind, the fact that the metric system is based on the earth's circumference makes the back-of-the-envelope approach easy. The arc from equator to pole is 10 000 km, so that 1 degree of latitude = 111 km.

Conversely, if global mean temperatures were to rise by a uniform 3°, climates would migrate towards the poles, on average by about 500km. The exception is that the extremely cold climate currently prevailing at the poles would disappear and that a new high temperature climate would prevail at the equator.

Only two assumptions in the analysis leading to Proposition 1 do not appear entirely robust. The first is that $L(T^1) = L(T^n) = 0$. In practice, nearly all regions of the earth are subject to some form of economic activity that is affected by climate. The assumption of zero economic value is reasonably accurate for the high latitudes (near the poles) where activity is constrained by low temperatures. On the other hand, some Equatorial areas yield considerable economic value. The violation of the assumption $L(T^1) = 0$ implies that the comparative static procedure should yield positive net estimates of benefits, since the area of usable land will actually be expanded by global warming.

The second assumption, implicit in the argument presented above, is that the total land area is constant. This is invalid, since global warming is generally expected to lead to a rise in sea levels. A rise of about 1 meter is expected as a result of expansion following rising water temperatures, combined with some melting of glaciers. A much greater rise (about 6 meters) would occur if the Antarctic ice sheet melted. Current scientific opinion is that this will not occur as a result of the warming anticipated over the next fifty years. These issues are discussed further in EPA (1989, Ch 7).

The process of adjusting to rising sea level may involve considerable economic costs. However, these are dynamic in nature, and will therefore be considered in the following section. The relevant consideration for comparative static analysis is the likely reduction in the world's land area. For a 1 meter sea level rise, the loss of land area is trivially small. For the US, EPA (1989) suggests that coastlines will move inwards by less than 0.5 km in most areas, implying a reduction in US land area of less than 0.1 %. Hence, this effect may be disregarded, except for a few very vulnerable countries (notably

Bangladesh, the Netherlands and some island states).

On the basis of these modifications of Proposition 1, it seems reasonable to conclude that any consistent application of the comparative static approach, using the consensus predictions of likely climatological impacts, must yield the conclusion that global warming will have zero (or perhaps slightly negative) net costs. No such consistent analysis appears to have been presented. As will be argued below, most published estimates involve a mixture of dynamic and comparative static reasoning.

The Dynamic Approach

The key difference in the dynamic approach lies in the treatment of capital stocks. In the comparative static approach, the capital stock is completely homogenous, both in form and in its allocation across regions. In the dynamic approach, capital is heterogeneous and location-specific. The basic approach is that of the 'putty-clay' model. Divergences in the marginal product of capital, arising in the present context from climatic change, call forth adjustment in the form of new investment in areas where the marginal product is high. In areas where the marginal product is low, the capital stock declines as a result of depreciation or, in extreme cases, scrappage. To provide a simple comparison with the comparative static approach, it will be useful to consider first the case when total capital stock is constant (new investment = depreciation in every period).

The production technology for region i is given by

$$Y_{it} = f(K_{i1t}, N_{i1t}) + f(K_{i2t}, K_{i3t}, \dots K_{imt}, N_{i2t}, \dots N_{imt}, L_i(T_{it})) \tag{3}$$

where K_{ijt} represents the stock of the j-th type of capital in region i at time t. As in the comparative static model, K_{i1t} represents the capital stock associated with activities that are independent of climate. The capital stock associated with climate-dependent activities has been disaggregated into stocks of (m-1) specific classes of capital. A similar disaggregation has been undertaken for labor.

Capital stocks evolve subject to the constraints that

(4) $$\sum_{i=1}^{n} \sum_{j=1}^{n} K_{ijt} = K \cdot t$$

and

(5) $$K_{ijt} \geq (1 - \gamma_{ij}) K_{ij(t-1)}$$

where

γ_{ij} is the rate of depreciation for the j-th type of capital in region *i*.

Suppose that the time path of climate T_{it} is known in advance for all *i*, *t*. The planning problem is to maximize an objective of the form

(6) $$V = \sum_{t=1}^{\tau} e^{-rt} \sum_{i=1}^{n} Y_{it}$$

subject to the constraints (4), (5). We shall denote the initial distribution of temperature by T_{i0} $i = 1 \ldots n$. As in the previous section, we assume that in the initial distribution, the areas of extreme temperature are valueless, so that $L_1(T_{10}) = L_n(T_{n0}) = 0$. Under appropriate uniformity conditions a small change in temperature will therefore have no effect on the total quantity of usable land, though it will alter the regional distribution. The initial stocks of capital and labor by K_{ij0}, $i = 1..n$, $j = 1..m$ and N_{i0} $i = 1 \ldots n$. It will be assumed that the system is initially in equilibrium so that the initial stocks of capital and labor are equal to the optimum derived in the previous section.

We now suppose that temperature increases by a constant amount δ per period. Thus, a comparative static analysis could be undertaken by fixing some τ (for example, the doubling time of global CO_2 stocks) and undertaking the analysis of the previous section with $\Delta = \delta\tau$. As we have seen, for moderate values of Δ, a zero net impact is derived.

We now turn to a dynamic analysis. Denote by K, N the time paths of the regional allocations of capital and labor and let

$$V^*(\delta) = Max_{K,N}\, V \tag{7}$$

where V is defined as in (6) and K satisfies the constraints (5). Our key result is

Proposition 2: Under the stated conditions V is a concave function of δ with maximum at zero.

Proof: By the initial equilibrium assumption, the optimal path when $\delta=0$ has $K_{ijt} = K_{ij0}\ \forall\ i, j, t$. Define the unconstrained optimal path for arbitrary δ by $K^{**}(\delta)$, and the associated return by $V^{**}(\delta)$. Then $V^{**}(\delta) \geq V^{*}(\delta)$. This inequality will be strict whenever any of the constraints is binding. By Proposition 1, $V^*(0) = V^{**}(\delta)$, so V^* takes its maximum at zero. Concavity follows from the properties of the production function.

It follows that the estimate of zero loss derived in Proposition 1 is, in fact, a lower bound. Under certainty the lower bound will be attained if and only if all of the required capital stock adjustments are consistent with the constraint (5). That is, in any region i where the stock of capital j is required to contract as T changes, the rate of adjustment needed to maintain optimality must be less than γ_{ij}.

This implies that there exists a range of rates of temperature change for which the net damage is zero. These rates of change are sufficiently slow that all relevant capital stocks can be costlessly adjusted to the changed distribution of climate, so that the comparative static analysis of the previous section applies. The faster is the rate of climatic change, the greater the number of classes of capital that cannot be adjusted in this optimal fashion and the greater the net costs.

Comparison of the two approaches

From the analysis above, the adoption of a dynamic approach yields a number of changes in the assessment of the costs of global warming. Most importantly, the comparative